Earth in the Universe

TOPIC 3

How Scientists Study Earth in the Universe

Do you think Earth's orbital shape and its variable distance from the sun is a major cause of Earth's seasons?

If you said yes, you might be surprised! Consider this: The shape of Earth's orbit is much closer to a circle than an oval. Yet there are small changes in Earth's distance from the sun throughout the year. Earth is farthest from the sun around July 4 when it is summer in the northern hemisphere. This doesn't make sense if Earth's distance from the sun is the reason it is sweltering outside.

The whole sky is 180 degrees from one horizon to the sky top to the opposite horizon. Angular degrees (°) can be divided into 60 minutes (′) and each minute divided into 60 seconds (″). Both the sun and the moon are about 0.5 degrees in apparent angular diameter, thus you could place about 360 suns or moons in the sky from horizon to horizon.

When the sun is closest to Earth around January 3, its apparent diameter is 0° 32′ 35″, and around July 4, the sun's apparent angular diameter is 0° 31′ 31″. The difference is 0° 01′ 04″, which is very small. Thus other factors must be the major cause of the seasons.

TOPIC 3

Earth in the Universe

Vocabulary

asteroid	gravitation	nuclear fusion
Big Bang theory	impact crater	red shift
celestial object	impact event	revolution
comet	inertia	rotation
Doppler effect	Jovian planet	solar system
eccentricity	luminosity (of a star)	star
ellipse	meteor	terrestrial planet
focus (pl., foci)	Milky Way Galaxy	universe
galaxy	moon	

Topic Overview

Throughout the ages, humans have observed the celestial objects in the sky and wondered about them. From Earth, a **celestial object** is any object outside or above Earth's atmosphere. There are about 6000 celestial objects visible with the unaided eye from any location on Earth. Where do people fit? Are they alone? Are there other solar systems with an environment in which humans could live? This topic focuses on our solar system, our galaxy, and the universe. In recent years there has been much discussion of and evidence for dark matter and dark energy, which may compose a major portion of the universe and our home Milky Way Galaxy. Dark matter and dark energy are not presently a part of this course of study.

Digging Deeper

To help you understand the Doppler effect, compare the Doppler effect of electromagnetic energy with that of sound waves. If you are standing on a street corner and a fire truck is coming towards you with the siren constantly blaring, the sound waves are bunched together as the truck gets closer to you. These shorter wavelengths are observed as a higher pitch or sound to your ears. After the truck passes, with the siren still blaring, the sound waves are stretched out (like the red shift). The sound has a lower pitch and sounds softer or muted.

Origin and Age of the Universe

Over the thousands of years of human thinking, various cultures have produced a multitude of theories concerning the origin, evolution, and structure of the universe. **Universe** means everything that exists in any place—all the space, matter, and energy in existence. The majority of scientists today think that the universe is extremely vast, and that it is more than 10 billion years old—maybe as many as 13.7 billion years old.

Presently, the majority of scientists believe that the universe began with an event called the Big Bang and has been expanding in volume ever since. The **Big Bang theory** states that all matter and energy started out concentrated in a small area and, after a gigantic explosion, matter began to organize into subatomic particles and atoms. Most, if not all, of the earliest atoms were hydrogen and helium. Within a few hundred million to a billion years, atoms became organized into celestial bodies, and then most stars became part of gravitational groupings. As this organization of matter was occurring, the universe kept expanding in all directions, and continues to expand at present.

Evidence for the Big Bang

Scientists have theorized that if a Big Bang did occur, the energy created by the explosion expanded along with the matter. Thus, there should be radiation from the Big Bang in all parts of the universe mixed with the energy given off by stars at later times. Recently, scientists have found evidence of long-wavelength background radiation—actually microwaves—that appear to be coming from all directions in the universe. This background radiation is evidence supporting the Big Bang theory.

Other evidence of the Big Bang is found in the spectrum of the radiation emitted by stars. Look over the Electromagnetic Spectrum in the *Earth Science Reference Tables.* The various types of waves that transmit energy Ⓡ through space are called electromagnetic energy. Each element emits energy in specific portions—wavelengths—within the electromagnetic spectrum. Because the human eye observes different wavelengths of visible light as different colors, people can distinguish specific portions of the electromagnetic spectrum. When scientists study the spectrum of electromagnetic energy coming from stars and other celestial objects, they can infer which elements are in these objects. Scientists base these inferences on the comparison of the signature wavelengths produced by elements on Earth with those coming from the other celestial objects.

Scientists have found that the position of the characteristic wavelengths, or colored lines, are shifted to either the shorter (blue end) or longer (red end) wavelengths. This shifting of wavelengths is called the **Doppler effect.** The relative movement between Earth and the other celestial object causes the Doppler effect. If Earth and another celestial object are coming closer together, the electromagnetic waves are bunched together, resulting in a blue shift Doppler effect. If Earth and some other celestial object are moving apart, the electromagnetic waves are spread out causing a **red shift** Doppler effect.

The collective light from the stars in all galaxies, except for a few galaxies close to Earth, is shifted to the red end of the spectrum. The fact that almost all galaxies have a red shift indicates that the universe is expanding in all

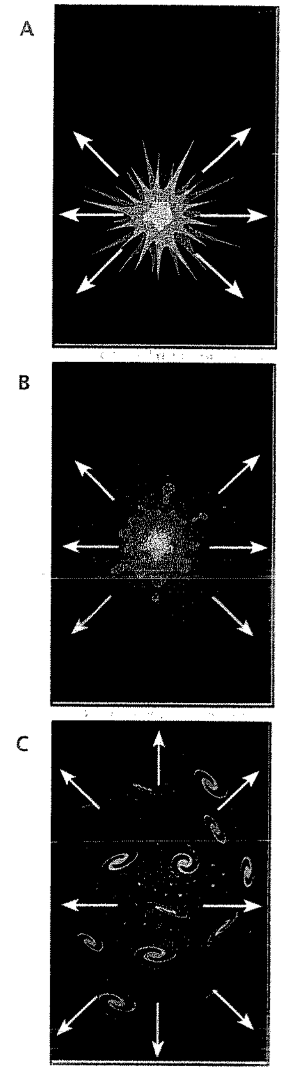


Figure 3-1. Big Bang and expanding universe: (A) Approximately 13.7 billion years ago, all mass and energy was concentrated in a small area that started expanding with a big explosion called the Big Bang. (B) The expanding, cooling universe first formed subatomic particles and finally small atoms of hydrogen and helium. (C) After approximately a few hundred million to a billion years, matter clumped together forming stars and early galaxies, and the universe kept expanding.

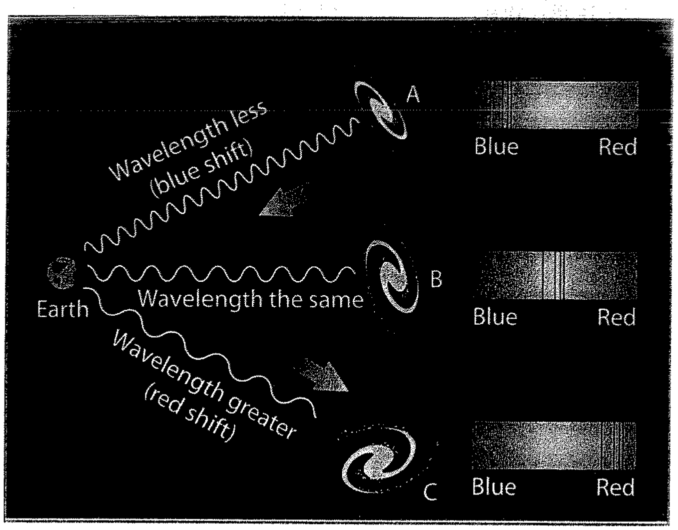


Figure 3-2. Doppler effect blue and red shifts: Galaxy B is not moving towards or away from Earth. The spectral lines of one element are the same as they would be if they were produced on Earth. Galaxy A is moving towards Earth—bunching up the light rays and shifting the spectral lines of the element to the blue end of the spectrum. Galaxy C is moving away from Earth—as most galaxies are—spreading out the light waves and shifting the spectral lines of the element to the red end—red shift.

directions. This evidence further supports the Big Bang theory and the expansion from the initial explosion. In addition, the farther away a galaxy is from Earth, the greater the red shift. This fact indicates that the rate of expansion of the universe is increasing.

Review Questions

1. From your location, what is the best definition of a celestial object?
   (1) any object in the universe
   (2) any object in the universe above Earth's atmosphere
   (3) any object in the universe outside our solar system
   (4) any object in the universe outside our home galaxy

2. The age of the universe is measured in 10 to 20
   (1) thousands of years
   (2) millions of years
   (3) billions of years
   (4) trillions of years

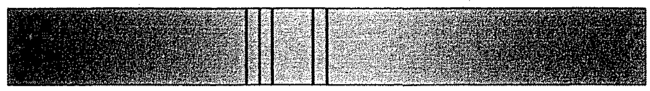
3. Studies of the universe generally indicate that
   (1) almost all galaxies appear to be moving away from Earth at tremendous velocities
   (2) few galaxies other than our own exist
   (3) all galaxies are approximately the same size
   (4) all galaxies are spiral in shape

4. Background radiation detected in space is believed to be evidence that
   (1) the universe began with an explosion
   (2) the universe is contracting
   (3) all matter in the universe is stationary
   (4) galaxies are evenly spaced throughout the universe

5. Which statement best describes how most galaxies generally move?
   (1) Galaxies move toward one another.
   (2) Galaxies move away from one another.
   (3) Galaxies move randomly.
   (4) Galaxies do not move.

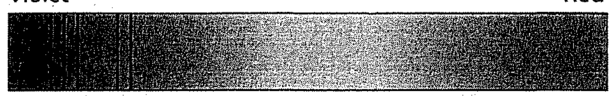
6. The following diagram represents a standard spectrum for an element.

Violet Red

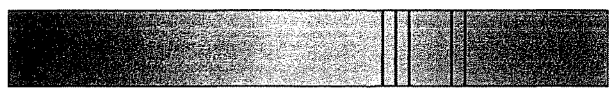


The spectral lines of this element are observed in light from a distant galaxy. Which diagram represents these spectral lines?

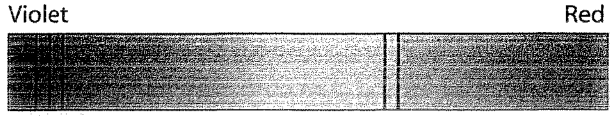
(1) Violet Red



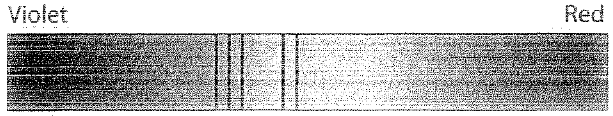
(2) Violet Red



(3) Violet Red



(4) Violet Red



Structure of the Universe

In recent years instruments such as the Hubble space telescope have allowed scientists to infer some basic structure to the known universe.

Galaxies

The basic structural unit of matter in the universe appears to be the galaxy. A **galaxy** is a collection of billions of stars and various amounts of gas and dust held together by gravity. An average galaxy will have over 100 billion

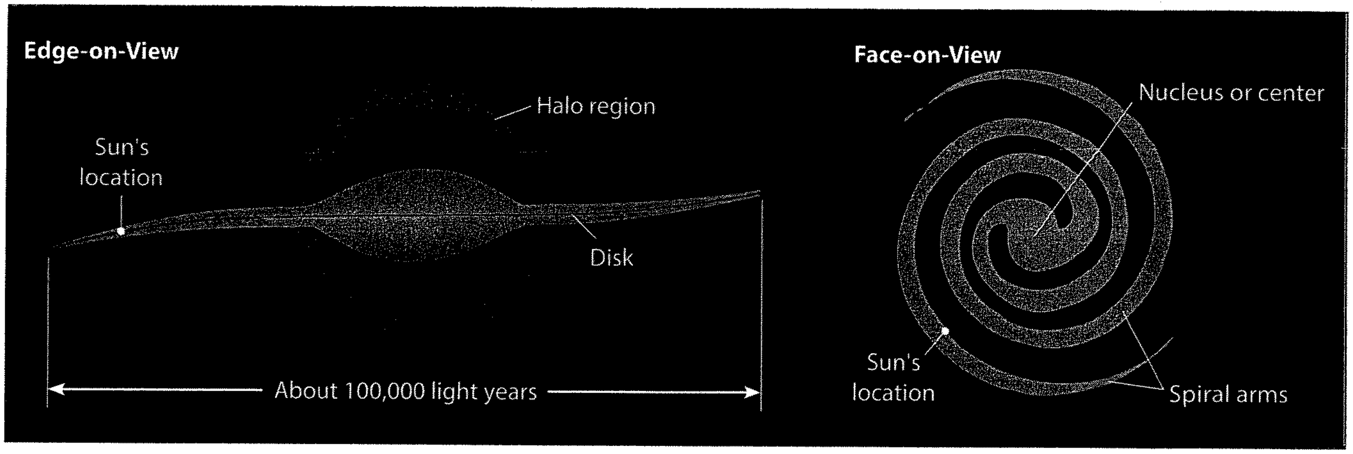


Figure 3-3. The Milky Way Galaxy: This spiral-shaped galaxy of which Earth is a part measures approximately 100,000 light years at its greatest diameter. Each light year is about 6 trillion miles or 9.5 trillion kilometers. The halo region is made up of clusters of stars that are billions of years older than our sun. The sun indicates our solar system's location near a spiral arm.

stars, and there are over 100 billion galaxies. Galaxies have been classified into a few types largely based on shape, including elliptical (football shaped), irregular, and spiral. Our solar system is a part of a spiral-shaped galaxy called the **Milky Way Galaxy,** which has over 200 billion stars. Figure 3-3 illustrates the spiral shape of the Milky Way Galaxy. It also shows the position of our solar system between two spiral arms about two-thirds of the distance out from the galactic center.

Stars

Along with dust and gas clouds, stars make up the majority of the visible matter in a galaxy. A **star** is usually a large ball of gas held together by gravity that produces tremendous amounts of energy and shines. There are many exceptions to this definition—some very old stars are the size of planets or moons, and some stars no longer emit much radiation. The star called the sun is the dominant gravitational force associated with Earth and the rest of our solar system.

Energy Production in Stars Most of the tremendous amounts of energy produced by most stars is the result of nuclear fusion in their cores. **Nuclear fusion** is the combining of the nuclei of smaller elements to form the nuclei of larger elements with some of the mass being converted into energy. As an example, the sun converts hydrogen nuclei into helium nuclei with about 0.07 percent of the mass forming energy. There are many other types of nuclear fusion that occur in stars of different ages or sizes than the sun. Nuclear fusion can only occur in extremely high temperature and high pressure conditions like those found in star interiors. The energy of nuclear fusion in most stars is eventually radiated into space as types of electromagnetic energy.

The Characteristics of Stars Diagram The classification scheme of grouping stars by surface temperature compared to their luminosity is shown in the Characteristics of Stars diagram in the *Earth Science Reference Tables.* (R) **Luminosity** is the actual brightness of a star or rate of total energy emitted compared to the Sun. It is measured as absolute magnitude, which is a star's brightness at a standard distance. What we directly observe when we look at stars is the apparent brightness, which is dependent upon the star's absolute luminosity and its distance away from us.

An analysis of a Characteristics of Stars diagram indicates that star properties are not random. Of the hundreds of thousands of stars plotted on the diagram, stars appear to be grouped by differences in luminosity and surface temperature as reflected by color. Just as the filament in a light bulb or the coil in an electric heater changes color with increasing temperatures, stars change color from red to blue as their surface temperatures increase.

Star Types Figure 3-4 illustrates the relative size differences in some of the star groups. The diameter of the sun—a medium-sized star—is 109 times the diameter of Earth. Most stars are much bigger than Earth, but some—such as neutron stars, black holes, and some dwarfs—are smaller than Earth. These smaller stars are actually shown too big in this diagram compared to the sun. Giant stars are 10 to 100 times the diameter of the sun, and super giants are 100 to 1000 times the diameter of the sun. Some of the star types commonly identified on a Characteristics of Stars diagram are described here.

Main Sequence Stars About 90 percent of studied stars are located on the Characteristics of Stars diagram in a broad band called the main sequence. Most stars spend the majority of their life span as a main sequence star. Most of these stars are average size, and as the surface temperatures of the stars increase, the luminosity increases. The luminosity increase from red to blue-white is mostly related to an increase in star size and the resulting higher temperatures. Our sun is a main sequence star of yellow color. The smallest and coolest stars of the main sequence are the very common type of star—the red dwarfs.

Giant Stars Red, orange, and yellow giant stars are a rare type of star but are commonly seen in the night sky because of their large size—10 times or more the diameter of the sun—and their high luminosity. These low-temperature stars represent a late stage in the evolution of medium to small-size main sequence stars—when they greatly expand in size.

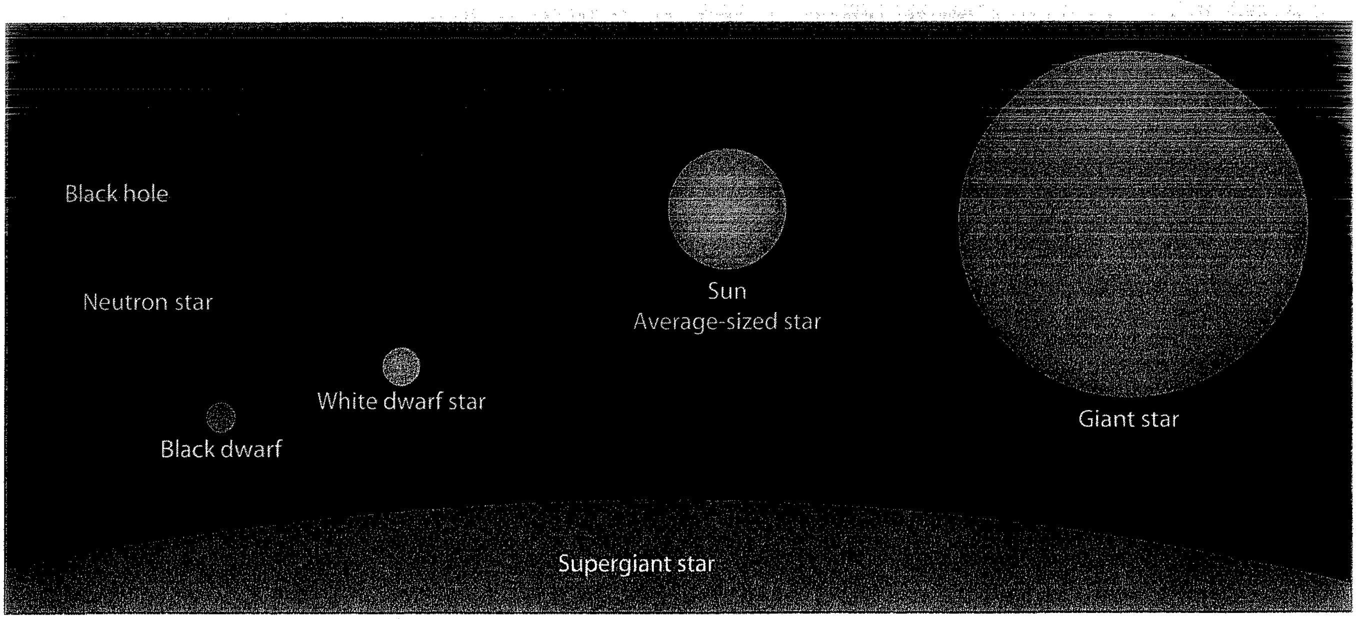


Figure 3-4. Relative sizes of stars: The smaller stars are not drawn to scale.

Super Giants Super giant stars can be anywhere from 100 to 1000 times the diameter of the sun. (See Figure 3-4.) These highly luminous stars represent the late evolution of stars much more massive than the sun. Super giants usually explode in a tremendous event called a supernova. The super giant stars that are the brightest and exhibit the highest temperature are the blue super giants.

White Dwarfs Not all white dwarf stars are white, but they are all small—around the size of Earth. They are hot on the surface and low in luminosity. They represent the last luminous or shining stage of low- to medium-mass stars.

Black Dwarfs When a white dwarf cools and no longer emits much electromagnetic energy, it is a "dead" star—a black dwarf. Black dwarfs are probably very common in the universe because in the many billion years of the existence of white dwarf stars, many trillions of them have stopped nuclear fusion and no longer produce nuclear energy.

Star Origin and Evolution Stars, like many objects on Earth, have an origin, an evolution of features, and an ending. Figure 3-5 models star evolution as partly shown in the Characteristics of Stars chart in the *Earth Science Reference Tables*. It is believed that stars originate from clouds of gas and dust molecules. These clouds were created from the masses that evolved from the original Big Bang and/or from the mass given off by stars that have expanded, exploded, or otherwise given off mass to space. Gravity causes these gas and dust clouds to clump up, forming larger and larger balls of gas and dust molecules. When the mass of these spherical balls becomes slightly larger than the planet Jupiter, the gravitational contraction results in high enough temperatures and pressure to start nuclear fusion. Then the ball begins to shine, or radiate large amounts of electromagnetic energy, and a star is born. (R)

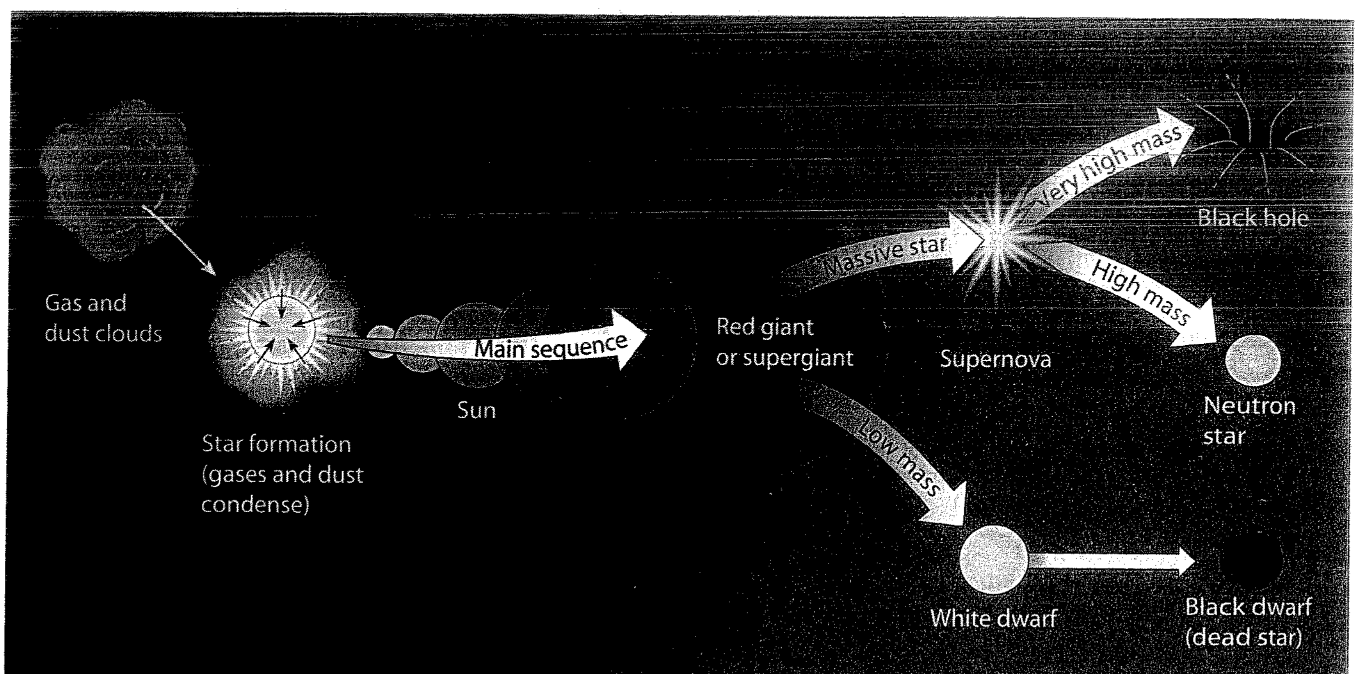


Figure 3-5. Model of star origin and evolution: The original mass of a star largely determines its evolutionary stages and how long it lasts.

The evolutionary stages of stars—after they spend most of their lives as a main sequence star—depends upon their original mass. Most stars with masses similar to the sun spend billions of years as a main sequence star and eventually expand to become a red giant. As the bottom part of Figure 3-5 shows, these stars use up most of their nuclear fuel and collapse to form a white dwarf, and then slowly "die" becoming a black dwarf. This process may take many billions of years, and some stars created soon after the Big Bang may still exist.

The evolution of stars with an original mass greater than one and a half times the mass of the sun is substantially different. These stars exist for much shorter periods of time—approximately 100,000,000 years. As the upper part of Figure 3-5 indicates, these massive stars evolve into super giants after spending time as a large main sequence star. They eventually explode in a supernova event and then rapidly collapse, forming a body much smaller than a white dwarf. They are so dense that only neutrons can exist, and a neutron star is formed. When even more massive stars collapse, the density is so great that it creates an extreme gravity field that allows no visible light or any other form of energy to escape, and a black hole is formed.

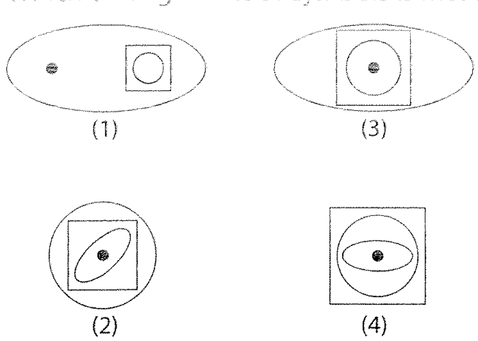
Review Questions

7. Billions of stars in the same region of the universe are called

(1) solar systems
(2) asteroid belts
(3) constellations
(4) galaxies

8. The following symbols represent the Milky Way Galaxy, the solar system, the sun, and the universe.

Which arrangement of symbols is most accurate?



9. In which group are the parts listed in order from oldest to youngest?

(1) solar system, Milky Way Galaxy, universe
(2) Milky Way Galaxy, solar system, universe
(3) universe, solar system, Milky Way Galaxy
(4) universe, Milky Way Galaxy, solar system

10. The great system of 200 billion stars to which the sun and our solar system belong is the

(1) Andromeda Galaxy
(2) Large Magellanic Galaxy
(3) Milky Way Galaxy
(4) Orion Nebula Galaxy

11. A star differs from a planet in that a star

(1) has a fixed orbit
(2) is self-luminous
(3) revolves about the sun
(4) shines by reflected light

12. The sun's energy is most likely the result of the

(1) fusion of hydrogen atoms
(2) transformation of the sun's gravitational potential energy to heat energy
(3) burning fossil fuels
(4) radioactive decay of uranium and thorium atoms

13. Nuclear fusion can only occur in areas of

(1) high temperature and low pressure
(2) high temperature and high pressure
(3) low temperature and low pressure
(4) low temperature and high pressure

14. As star color changes from blue to red, the surface temperature of the star

(1) decreases
(2) increases
(3) remains the same

15. A luminosity and temperature of stars diagram classifies a star of high temperature and low luminosity as a

(1) giant (3) supergiant
(2) main sequence star (4) white dwarf

Base your answers to questions 16 through 23 on the Characteristics of Stars diagram in the *Earth Science Reference Tables.*

16. A main sequence star is 1000 times more luminous than the sun. The temperature is likely to be most nearly

(1) 3000 K (3) 12,000 K
(2) 5000 K (4) 25,000 K

17. A giant star has a luminosity of 300. Its color is most likely to be

(1) yellow-red (3) white
(2) black (4) blue-white

18. A white dwarf star has a temperature of 13,000 K. What is the probable luminosity of the star?

(1) 100 (2) 10 (3) 0.1 (4) 0.01

19. An orange star has a temperature of 4000 K and is 500,000 times as luminous as the sun. To which group does it belong?

(1) giants (3) white dwarfs
(2) supergiants (4) main sequence

20. The nearest star to the sun is Alpha Centauri. How does this star compare to the sun?

(1) It is much hotter.
(2) It has a different color.
(3) It has a higher luminosity.
(4) It is much smaller in diameter.

21. The sun is best described as a

(1) very large star (3) red star
(2) medium-sized star (4) cool star

22. The sun is brighter than any star in the group of

(1) supergiants (3) main sequence stars
(2) giants (4) white dwarfs

23. Which type of star is associated with the last stage in the evolutionary development of most stars?

(1) main sequence star (3) giant
(2) supergiant (4) white dwarf

Solar System

In the last few years, powerful telescopes on Earth and in space have found evidence of planets around more than 100 stars. This means that "solar system" really can refer to any star or group of two or three stars that has non-star objects orbiting it. However, in this book, the solar system is our **solar system**—the sun and all objects that orbit the sun under its gravitational influence.

Parts of the Solar System

Most of the solar system is space devoid of much mass. However, about 99 percent of the mass that does exist is contained in the sun. The sun is a medium-sized, main sequence star about 5 billion years old that is the gravitational center of our solar system. A satellite is any object that orbits or revolves around another object. The planets, asteroids, meteoroids, and comets are satellites of the sun, and the moons are satellites of planets or asteroids. Earth has one natural satellite—the moon—and more than 2,500 artificial ones.

Planets The eight planets are the largest objects that independently orbit the sun and don't share their environment with other large objects. Planets are generally spherical in shape. The planets will be described in more detail later in this topic. Recently, over 1000 planets have been found revolving around stars other than our sun.

Digging Deeper

In recent years astronomers have discovered two portions of our solar system beyond the orbit of Neptune. The Kuiper Belt is a region of the solar system that is generally in the plane of the planets beyond Neptune that includes Pluto and many other dwarf planets, some even larger than Pluto, moons, and comets. Many of the comets that come into the inner parts of the solar system are believed to originate in the Kuiper Belt. The Kuiper Belt is believed to extend out about 1000 times Earth's distance from the sun.

The Oort Cloud is a vast "cloud" or sphere of likely millions of comet-like bodies that surround the rest of the solar system, and may extend out from Neptune's orbit 50,000 to 100,000 times the distance of the Earth to the sun. It may even reach out to where the influence of the sun blends with that of other stars.

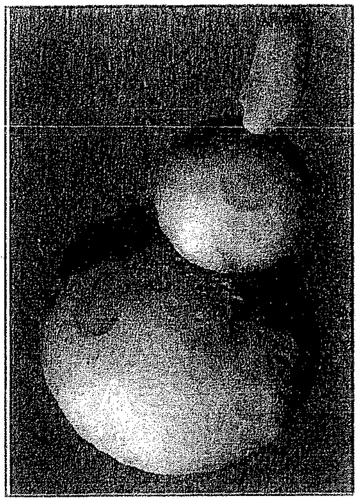


Figure 3-6. Composite images of 3 asteroids: These three images are at different scales. The three asteroids are all in the main asteroid belt located between the orbits of Mars and Jupiter. Ceres, the largest asteroid at the bottom, with an average diameter of about 940 km, has recently been classified as a dwarf planet due to its size and spherical shape. Vesta's average diameter is about 535 km, and is shown in the middle. Ida, the smallest at the top, has a more typical irregular asteroid shape and its largest "diameter" is about 56 km. Note the high density of impact craters on all three asteroids.

Asteroids An **asteroid** is a solid rocky and/or metallic body that independently orbits the sun. Asteroids have an irregular shape, except for the larger ones which are spherical, and no atmosphere. (See Figure 3-6.) A large percentage of the thousands of known asteroids are in orbits between Mars and Jupiter. Asteroids are smaller than planets (from about 100 to 1000 kilometers in diameter) and are often called minor planets.

Moons A **moon** is a body that orbits a planet or an asteroid as those objects orbit the sun. There are approximately 175 known moons, which vary in size from larger than the smallest planets to only a few kilometers in diameter.

Comets A **comet** is often compared to a snowball made from snow found along a road that has just been sanded—a dirty snowball. Comets are mainly composed of solids that easily change to gases when heated. They are largely ices of substances such as water and methane mixed with rocky or metallic solids. Most comets are only 1 to 100 kilometers in diameter. When comets get near the sun, some of their ices turn to gases. Some solids are released, forming spectacular tails visible in Earth's sky, sometimes for weeks at a time. (See Figure 3-7.)

Meteoroids Very small solid fragments that orbit the sun are called meteoroids. Most meteoroids are only the size of a dime or sand grain. When meteoroids burn up or vaporize, they leave a brief visual streak as they pass through Earth's atmosphere and are called **meteors.** If a meteoroid survives its trip through Earth's atmosphere and lands on Earth's surface, it is then called a meteorite. Some meteorites have sufficient mass to create a depression in Earth's crust called an **impact crater.**

Evolution of the Solar System

Scientists infer that our solar system started to form approximately 5 billion years ago. At first there was a gas dust cloud many times the size of the present solar system. This cloud contained remnants of stars that had exploded, giving to the cloud heavier elements to mix with the more common lighter ones. Gravitation, perhaps aided by a shock wave from an exploding star, caused the cloud to condense into one or more mass concentrations. Look at Figure 3-8 and read the caption to see how these masses may have formed our solar system.

Figure 3-7. Comet near the sun: When the orbit of a comet brings it near the sun some of the solids are vaporized or are blown off the comet forming one or more tails.

Even after Earth and other planets formed, their gravitational forces pulled on the smaller clumps of matter to cause comets, asteroids, and meteoroids to collide with the planets in what is called an **impact event.** The planets, asteroids, and moons with solid surfaces bear witness to these impact events in the form of craters. Impact events have also been linked to global climate changes and mass extinctions.

Meteorites still hit Earth, and there is concern that this type of natural disaster could destroy a large portion of the life on our planet. Presently, an intensive scientific search is being conducted to find comets, asteroids, and meteoroids that could collide with Earth and have enough mass to result in loss of life, injury, and loss of property.

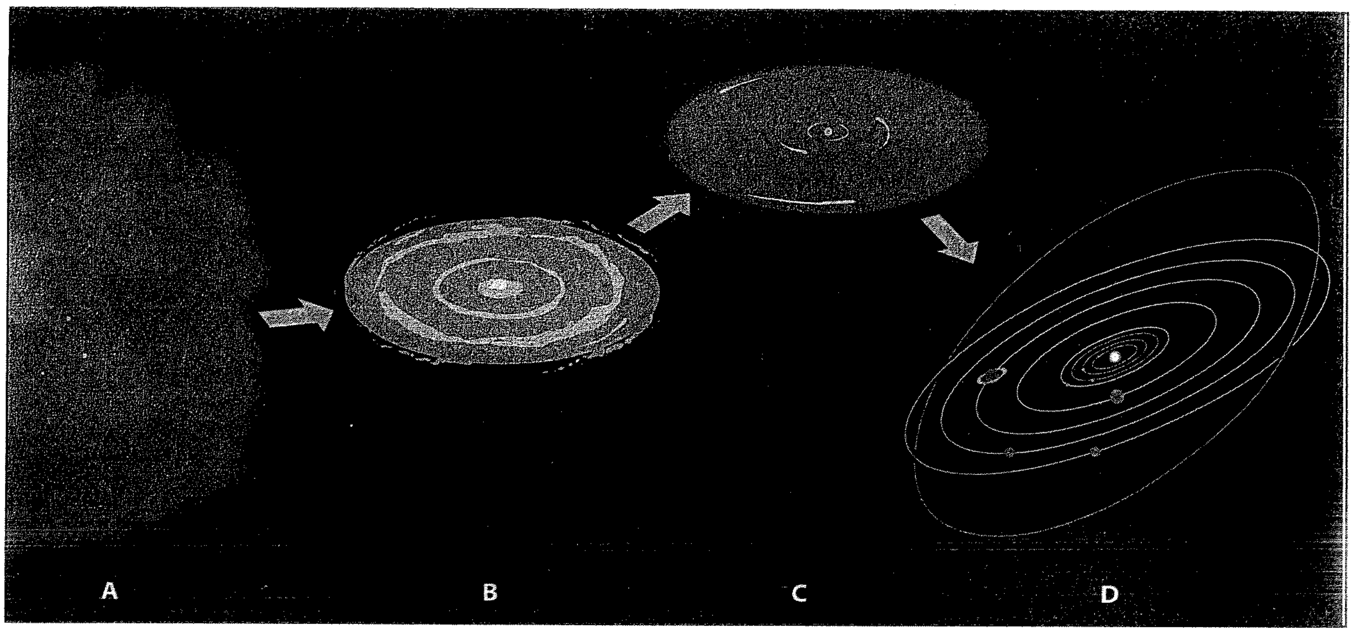


Figure 3-8. Theory of our solar system's formation: At stage A, a shock wave started a gravitational contraction of a gas-dust cloud. At stage B, most of the matter was pulled to the center to form the sun, which started nuclear fusion. Clumping of gas and dust around the sun occurred at the same time. At stage C, larger and larger clumps formed still larger masses—forming planets, moons, and asteroids. Elements having a small mass were driven out of the inner solar system leaving the terrestrial planets with only small amounts of light elements. By stage D, the solar system was similar to what it is today.

The gravitational contraction of the planets, larger asteroids, and larger moons produced heat. This heat, along with the heat from radioactive decay and frictional heat from impacting meteorites, caused the newly formed planets, larger asteroids, and moons to largely melt. As a result, these bodies became layered into zones based on the density of their various elements and compounds.

Review Questions

24. Comets are considered to belong to the solar system if they
    (1) glow by reflected light
    (2) revolve about the sun
    (3) have elliptical orbits
    (4) have uniform periods of revolution

25. A person observes that a bright object streaks across the nighttime sky in a few seconds. What is this object most likely to be?
    (1) a comet
    (2) a meteor
    (3) an explosion on the sun
    (4) an orbiting satellite

26. A belt of asteroids is located an average distance of 503 million kilometers from the sun. Between which two planets is this belt located?
    (1) Mars and Jupiter
    (2) Mars and Earth
    (3) Jupiter and Saturn
    (4) Saturn and Uranus

27. Which is not included in our solar system?
    (1) Polaris
    (2) the moon
    (3) meteors
    (4) asteroids

28. In the last billion years when meteorites, asteroids, or comets collided with Earth, which has occurred?
    (1) Craters have formed.
    (2) The whole Earth's surface has melted.
    (3) All life has been destroyed.
    (4) The oceans have largely evaporated.

29. Today it is most commonly believed that our solar system formed
    (1) by gravitational collapse of a gas-dust "cloud"
    (2) from material exploded from the sun
    (3) at the time of the Big Bang that formed the present universe
    (4) by fusion of matter between the sun and a passing star

Planet Characteristics

A planet's distance from the sun has a major effect on its characteristics. Ⓡ See the Solar System Data in the *Earth Science Reference Tables* to find each planet's distance from the sun and other significant features and events. When the planets were forming, the sun probably radiated more energy than it does today. The high temperatures and pressure from particles emitted by the sun drove the less dense elements and compounds away from the inner solar system. The outer parts of the solar system were not nearly so hot, and the particle pressure from the sun not nearly so great. These differences in the inner and outer solar system provide characteristics that allow the planets to be classified into the inner terrestrial planets and outer Jovian planets. The former planet Pluto, because of its small size and its composition similar to comets and other distant solar system members, doesn't fit either planet classification and is now called a "dwarf planet."

Terrestrial Planet Properties The **terrestrial planets** are close to the sun and mostly solid. They have relatively small diameters and high densities. Their rocky surfaces are dotted with impact craters. They have few or no moons and have no rings. Terrestrial planets are the planets similar to Earth and include Mercury, Venus, Earth, and Mars.

Jovian Planet Properties The **Jovian planets** are far from the sun and are largely gaseous. They have relatively large diameters and low densities. They have no solid surfaces (though they may have a solid core) and thus no craters. These planets have many moons and have rings. The Jovian planets are the planets similar to Jupiter and include Jupiter, Saturn, Uranus, and Neptune.

Motions of the Planets

The planets have many different motions. They move with the solar system around the Milky Way Galaxy in periods of about 225 million years.

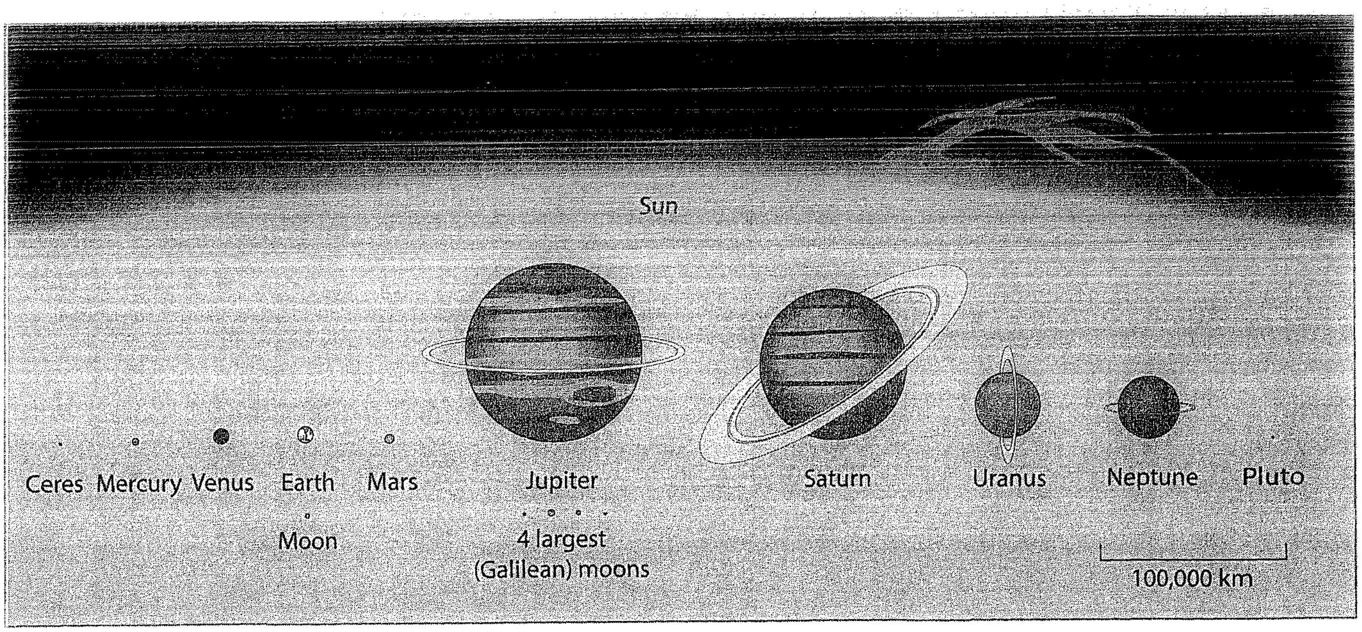


Figure 3-2. Comparison of the size (diameters) of the planets and some other solar system members: The diameter of Jupiter is about 10 times that of Earth, and the diameter of the sun is a little over 100 times that of Earth. The largest moon of Jupiter is larger than Mercury. The former planet Pluto and former largest asteroid Ceres are now called dwarf planets.

They rotate, or spin around an imaginary axis, and they revolve around the sun in an orbit, or path.

Memory Jogger

You may recall that the length of a day on Earth is not the same as the length of a day on other planets. Since each planet has a different period of rotation, the length of a day varies from planet to planet.

Planet Rotation Planets spin on an imaginary axis in a motion called **rotation.** The period of rotation is the amount of time it takes for a planet to make one spin around its imaginary axis and determines the length of a planet's day. Six of the eight planets rotate in the same direction as they revolve around the sun. You can tell that planets rotate through observations of surface features made at different times. The Solar System Data Table in the *Earth Science Reference Tables* lists the periods of rotation of the planets.

Planet Revolution A planet's **revolution** is its movement around the sun in a path called an orbit. The planets revolve around the Sun in a counterclockwise direction as viewed from Polaris. Earth's orbit (and those of the other planets) is an oval shape called an **ellipse.** Within the ellipse are two fixed points called **foci** (singular, **focus**). The sum of the distances between any point on the ellipse and the two foci is a constant; that is, the sum of those distances for one point is equal to the sum for any other point on the curve. The sun is at one of the foci of each planetary orbit in the solar system. (See Figure 3-10.) The major axis of an ellipse is the longest straight-line distance across an ellipse—the biggest diameter—and it cuts through the two foci.

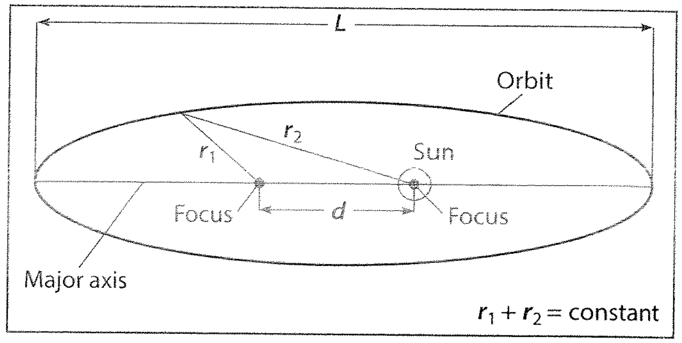


Figure 3-10. An elliptical orbit of a solar system member with the sun at one focus: Except for Mercury, the orbits of the planets would appear to look like a circle at this scale. The eccentricity of the ellipse is 0.26 (d = 2.0 cm and L = 7.7 cm; $\frac{2}{7.7}$ = 0.26).

Eccentricity of Planet Orbits The degree of flattening or "ovalness" of an ellipse is measured by its **eccentricity.** Eccentricity can also be described as the amount of difference between an ellipse as compared to a special type of ellipse called a circle. The formula to compute eccentricity is listed below and also in the *Earth Science Reference Tables*.

$$\text{eccentricity of an ellipse} = \frac{\text{distance between foci}}{\text{length of major axis}} = \frac{d}{L}$$

If you measure d and L in the ellipse of Figure 3-10 and apply the formula, you should find the eccentricity to be 0.26. As the foci of an ellipse are brought closer together, the ellipse becomes more like a circle and the eccentricity decreases toward zero. The eccentricities of the planets are listed in the Solar System Data in the *Earth Science Reference Tables*. If you were to draw the orbits of the planets to scale they would look like circles to the human eye, except for Mercury. As an example, Figure 3-11 shows Earth's orbit nearly drawn to scale, and it appears to be a circle.

Varying Distance of Planets from the Sun and Apparent Solar Size The elliptical shape of planetary orbits causes the planets to vary in distance from the sun during a revolution. For example, Earth is 147,000,000 kilometers from the sun when closest (occurring on or about January 3). Earth is 152,000,000 kilometers from the sun when farthest away (occurring on or about July 4). The difference between these two distances is only about 5,000,000 km. It is important to note that this is NOT the factor that causes seasons on Earth.

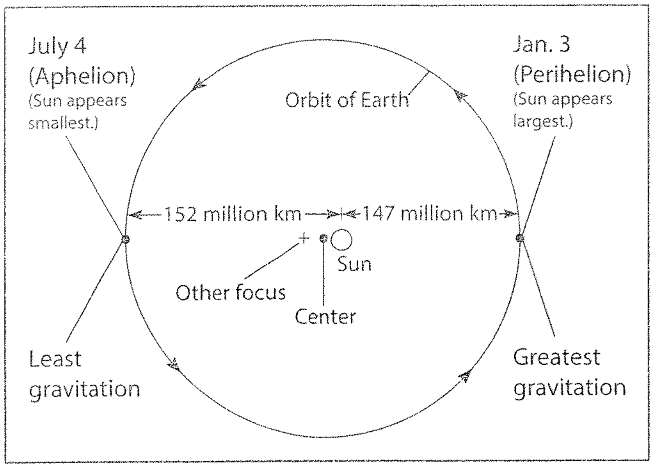


Figure 3-11. Earth's orbit drawn close to true scale: If the orbit were drawn to true scale, the two foci would be about 1 mm apart. Even at this exaggerated scale, with a greater eccentricity, the orbit appears to be a circle—thus Earth's orbit of the sun is a slightly eccentric ellipse.

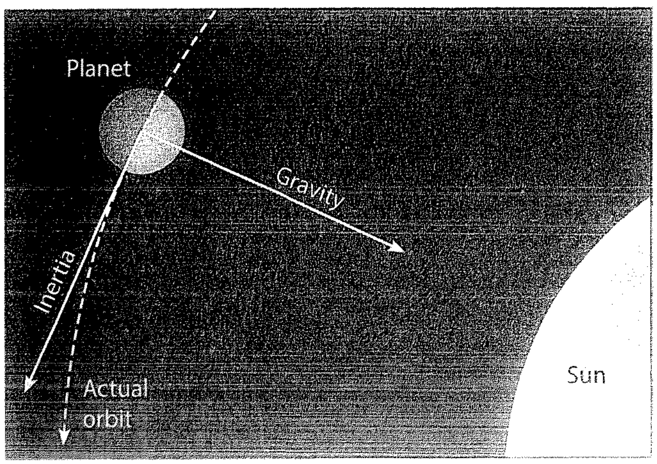


Figure 3-12. Balance between inertia and gravitation in revolution: Inertia would make a planet travel in a straight line. The mutual gravitation between the sun and a planet would pull the planet towards the sun. The actual orbit is a balance between the actions of inertia and gravity.

As Earth revolves around the sun the varying distance between the two bodies results in changes in the apparent size (diameter) of the sun as viewed from Earth. Photographs taken of the sun when Earth is closest to the sun, around January 3, illustrate that the sun appears largest on this date and smallest around July 4, when the distance between Earth and the sun is the longest.

Inertia, Gravitation, Orbital Velocity/Speed, and Planet Orbits The planets and all other bodies that orbit the sun, or any revolving body, operate under a balance between inertia and gravitation as shown in Figure 3-12. **Inertia** is the concept that an object at rest will tend to remain at rest, and that an object in motion will maintain the direction and speed of that motion unless an opposing force affects it. **Gravitation** is the attractive force that exists between any two objects in the universe. The gravitational force is proportional to the product of the masses of the objects and inversely proportional to the square of the distance between their centers. In simple terms, the greater the mass of one or both objects (such as a star and a planet), the more gravitational attraction there is between the objects. Also the closer together two objects are, the greater the gravitational attraction between them. Conversely, the farther apart two objects are, the lower the gravitational attraction between them.

The orbit of a planet around the sun, or that of any other satellite, is an example of the dynamic equilibrium, or balance, between inertia and gravitation. The shape and size of the orbit is a compromise, or balance, between the forces as illustrated in Figure 3-12.

Since each planet's orbit has some eccentricity, its distance from the sun varies during its yearly revolution. The result is that each planet's orbital speed velocity varies during its year. When a planet is closer to the sun, its orbital speed velocity is greatest, and when a planet is farthest from the sun, its orbital speed velocity is slowest.

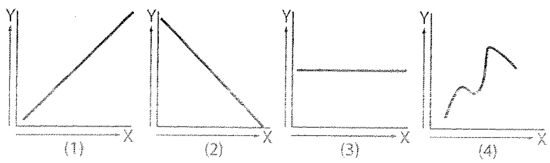
The period of revolution for a planet is the amount of time it takes the planet to make one orbit, or revolution, around the sun. This amount of time equals one <u>year</u> for that planet. The period of revolution of a planet is related to the planet's distance from the sun. The closer a planet is to the sun, the smaller its orbit, the shorter its period of revolution, and the faster its speed of revolution. Thus the time it takes for a planet, or any other member of the solar system, to orbit the sun is affected by two factors. The farther a planet is from the sun, the longer the orbital path that must be traveled in one year. Also, the farther a planet is from the sun, the less mutual gravitational attraction between the two objects and thus a slower orbital velocity.

Review Questions

30. The Jovian planets have more gravitational pull than the terrestrial planets. Therefore, they have

(1) a shorter year
(2) higher average density
(3) higher surface temperatures
(4) more low-density gases in their atmosphere

Base your answers to questions 31 and 32 on the following graphs. The first variable mentioned is on the Y-axis and the second is on the X-axis.



31. Which graph best illustrates the relationship between the diameter of a planet versus the distance of the planet from the sun?

32. Which graph best illustrates the relationship between the time it takes a planet to make one revolution around the sun versus the distance of the planet from the sun?

---

33. The planet that has the shortest day is

(1) Mercury (3) Jupiter
(2) Earth (4) Uranus

34. Which member of the solar system has an equatorial diameter of 3.48×10^3 kilometers?

(1) the moon (3) the sun
(2) Earth (4) Mercury

35. The planets known as "gas giants," or Jovians, include Jupiter, Uranus, and

(1) Mercury (3) Mars
(2) Saturn (4) Earth

36. Which three planets are known as terrestrial planets because of their high density and rocky composition?

(1) Venus, Neptune, and Mercury
(2) Venus, Saturn, and Neptune
(3) Jupiter, Saturn, and Uranus
(4) Mercury, Mars, and Venus

37. Astronomers have observed a reddish spot on the surface of Jupiter. From observations of this spot, it is possible to estimate the

(1) period of Jupiter's rotation
(2) period of Jupiter's revolution
(3) pressure of Jupiter's atmosphere
(4) temperature of Jupiter's surface

38. Which planet takes longer for one spin on its axis than for one orbit around the sun?

(1) Mercury (3) Earth
(2) Venus (4) Mars

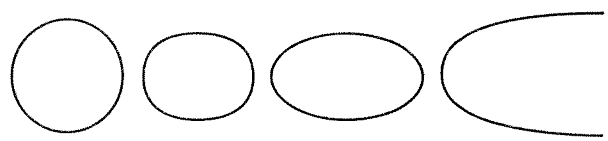
39. Which planet revolves fastest in its orbit?

(1) Earth (3) Mercury
(2) Jupiter (4) Neptune

40. In our solar system, the orbits of the planets are best described as

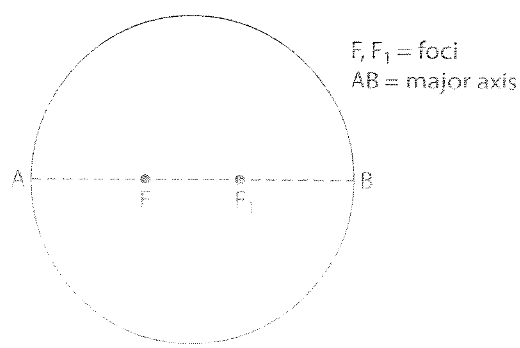
(1) circular, with the planet at the center
(2) circular, with the sun at the center
(3) elliptical, with the planet at one of the foci
(4) elliptical, with the sun at one of the foci

41. Which diagram best approximates the shape of the path of Earth as it travels around the sun?



(1) (2) (3) (4)

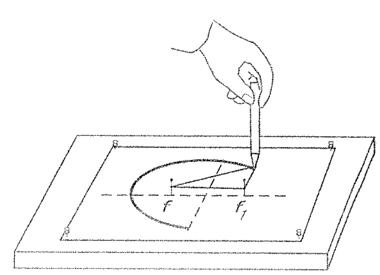
42. Based on the following diagram, what is the eccentricity of the ellipse in the diagram?



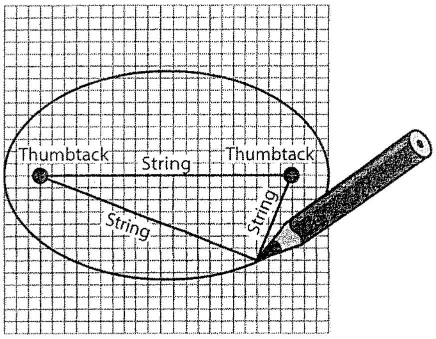
(1) 1.0 (2) 0.5 (3) 0.30 (4) 0.13

43. If the pins in the following diagram were placed closer together, the eccentricity of the ellipse being constructed would

(1) decrease (2) increase (3) remain the same



44. The following diagram represents a student's constructed laboratory drawing.

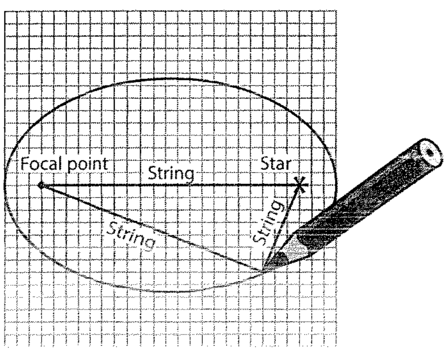


(Not drawn to scale.)

The student's drawing best represents the

(1) shape of Earth's moon
(2) shape of an elliptical orbit
(3) path of an earthquake wave
(4) path of a projectile deflected by Earth's rotation

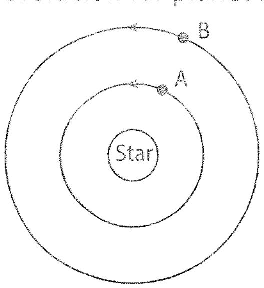
45. The following diagram represents the construction of a model of an elliptical orbit of a planet traveling around a star.



The focal point and the center of the star represent the foci of the orbit. The eccentricity of this orbit is approximately

(1) 1.3 (2) 0.8 (3) 0.5 (4) 0.3

46. The following diagram shows the orbits of planets A and B in a star-planet system. The period of revolution for planet B is 40 days.



The period of revolution for planet A most likely is

(1) less than 40 days
(2) greater than 40 days
(3) 40 days

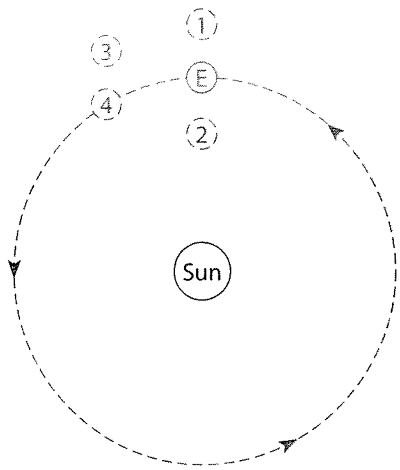
47. Which planet's orbit is most nearly circular?

(1) Earth
(2) Venus
(3) Neptune
(4) Jupiter

48. As the distance between two objects in the universe increases, the gravitational attraction between these two objects

(1) decreases
(2) increases
(3) remains the same

49. The diagram shows Earth (E) in orbit about the sun.



(Not drawn to scale.)

If the gravitational force between Earth and the sun were suddenly eliminated, toward which position would Earth then move?

(1) 1
(2) 2
(3) 3
(4) 4

50. The force of gravity between two objects is greatest when

(1) masses are small and the objects are close together
(2) masses are small and the objects are far apart
(3) masses are large and the objects are close together
(4) masses are large and the objects are far apart